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published in
International Journal of Behavioral Development
2003

DOI (link to publisher)
10.1080/01650250344000037

document version
Publisher's PDF, also known as Version of record

International Journal of Behavioral Development
2003, 27 (4), 366–374
http://www.tandf.co.uk/journals/pp/01650254.html

DOI: 10.1080/01650250344000037

Children's understanding of inherited resemblance: The case of two parents

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Four-, 6-, and 10-year-old children were tested in a forced-choice procedure about their beliefs on the inheritance of physical characteristics. They were presented with pictures of two biological parents, and then asked to select the most likely descendant out of three alternatives: a father look-alike, a mother look-alike, and an alternative representing the combined influence of both parents. In several question pairs, additional information was given about the parent–child relationship that was clearly irrelevant to the principles of heredity to examine the extent to which domain confusions were likely to occur. The majority of the 10-year-olds consistently preferred the alternative in which the combined influence of both parents was shown and domain confusions hardly ever occurred. Four- and 6-year-olds, in contrast, were still influenced by information from alien domains, although even their reasoning about inheritance seemed to be theory-like. Overall, the results suggest that with age, children develop a more restricted and better-defined conception of the principles of heredity, in which the combined influence of both parents is acknowledged.

There is ample evidence that even pre-school children believe that babies (including animal babies) resemble their parents (e.g., Carey, 1985; Gelman & Wellman, 1991; Hirschfeld, 1995; Johnson & Solomon, 1997; Springer, 1992; Springer & Keil, 1989). Cats have kittens (rather than puppies) and black people are expected to have black children. Of course, closer inspection of parents and their offspring reveals that there are not only similarities, but also differences. However, the child's general ideas of resemblance do not seem to be severely hampered by this phenomenon. The cute, harmless cub with its big round head looks quite different from the adult tiger, but is nonetheless expected to become just like his fierce and dangerous father later on, even by 4-year-olds (Taylor & Gelman, 1991).

When asked where children's ideas of family resemblance come from, we may be tempted to refer to the role of direct observation. However, family resemblance has proved to be something that is hard to observe on the basis of physical appearance only. True, parents with blue eyes tend to have children with blue eyes. But, it is equally true that this rule is often violated. In fact, the numerous discrepancies make it very hard to link parent and child correctly on appearance only (Christenfeld & Hill, 1995).

That young children nonetheless believe that parent and child resemble each other suggests that their reasoning is not, or at least not completely, appearance-bound. Indeed, there is mounting evidence that sustains this conclusion (e.g., Gelman & Markman, 1987; Keil, 1989). For instance, it has been shown that children apply their beliefs about resemblance not only to qualities that can be observed, but also to nonvisible characteristics. Four- and 5-year-olds already argue that children inherit not only their parent's "big eyes" but also their nonobservable "pink heart inside" (Springer & Keil, 1989).

Clearly, empirical evidence suggests that children endorse the general rule that parents and children are somehow the same. The question now becomes how they apply this general rule of "sameness". Since sexual procreation involves more than one parent, exact copies of one of the parents are hardly to be expected. The combined genetic influence of both parents is bound to create genetic variance in their offspring. The simple notion that "like begets like" (Springer & Keil, 1989) provides an adequate rule for the more general notion of family resemblance (Johnson & Solomon, 1997; Springer, 1995, 1996, 1999; Springer & Keil, 1989). But in inheritance the principle has to be adapted to the (complex) case of two parents. Of course, we do not expect children to possess full knowledge of Mendel's laws. Rather, we would like to know whether they have some naive understanding of the effects of a combined genetic influence. If this is the case, we would expect them to consider a descendant with the combined characteristics of both parents to be a more likely genetic product than an exact copy of one of the parents.

In previous research, it has already been argued that one cannot conclude that young children really understand the inheritance of properties simply from the fact that they expect a resemblance between parent(s) and offspring. It has to be established that they understand the autonomous character of the underlying mechanism: the fact that resemblance is based on nothing other than genetics (Carey & Spelke, 1994). The procedure used most often to test children's knowledge in this respect is one in which children have to argue that properties are inherited from a biological parent, but not from a close friend of the family (Springer, 1992) or an adoptive parent

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The authors wish to thank Inge van Dillen for her assistance in collecting the data, Jan B. Hoeksma for his statistical advice, and Anna Brett for correcting the manuscript.

(Solomon, Johnson, Zaitchik, & Carey, 1996; Springer, 1996). Here we use a slightly different approach. In order to examine children's understanding of the combined genetic contribution of both biological parents, our participants are confronted with two biological parents with different physical characteristics. In addition, a characteristic from a nongenetic domain is ascribed to one parent but not the other. In the case of an additional social variable, for instance, the subjects are told that one of the parents has actively raised the child, whereas the other has left immediately after birth. The subject is then asked to select the most likely offspring out of three alternatives: a carbon copy of the mother, a carbon copy of the father, or a third alternative that shows a combination of parental characteristics (see Figure 1). A choice for the third alternative is to be expected if (1) children are able to refrain from a simple "like parent, like child" rule (that would mandate them to choose the exact copy of either the mother or the father) and favour an "imperfect match" representing the combined influence of both parents, and (2) if children acknowledge the influence of two biological parents, irrespective of information from domains irrelevant to the issue of inheritance (e.g., taking part in the child-rearing process). However, if domain confusion takes place (i.e., if children consider the additional information to be pertinent to the issue of inherited resemblance), children are expected to favour the parent who is credited with the additional characteristic.

Previous experiments on domain confusion were limited to a possible confounding with the social (e.g., social proximity) and psychological (e.g., parental desires) domain (Carey, 1995; Hirschfeld & Gelman, 1994; Inagaki, 1997; Keil, 1994; Piaget, 1929; Solomon et al., 1996; Springer, 1992, 1995, 1999; Wellman & Gelman, 1992). Here, we also address two other possible misconceptions that were first reported in an interview study by Karbo, Hobbs, and Erickson (1980): the genetic dominance of the mother and the overgeneralisation of the gender factor. According to these authors, young children seem to think that mothers contribute more to the genetic make-up of the offspring than fathers (see also Clough & Wood-Robinson, 1985; Springer, 1999). They suggest that this bias is because of the mother's more salient role in procreation (see also Springer, 1996, 1999). However, physical proximity (children come from "their mother's tummy") may not be the only reason. Social proximity (mothers are normally the dominant caretaker) could be an alternative or additional factor.

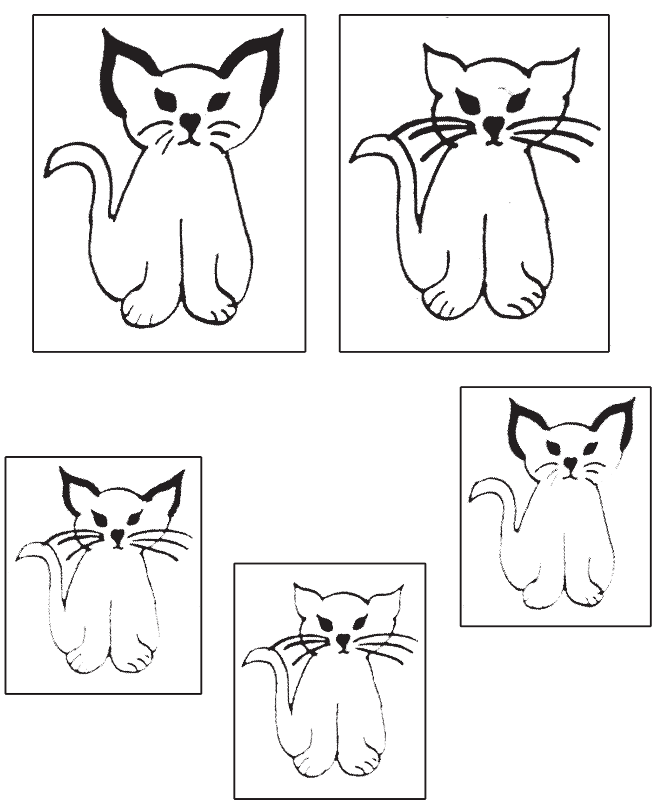

Figure 1. Example of the pictural material (pair I, question 1).

Karbo et al. (1980) have also demonstrated that some of their respondents think of the same-sex parent as being the most influential: sons resemble their fathers, whereas daughters resemble their mothers. Again, this simple rule may originate from two distinct types of overgeneralisations. First, a biological one, which concerns the overgeneralisation of primary gender characteristics. Or, alternatively, a cultural or social one, which refers to the overgeneralisation of social conventions: males wear trousers, whereas females wear skirts; males have short hair, whereas females have long hair.

In sum, this study aims to answer two related questions: (1) To what extent do children of different ages (4-, 6-, and 10-year-olds) have an intuitive understanding of inherited resemblance as being the result of the combined influence of both biological parents? and (2) To what extent do they acknowledge the autonomous character of the domain of heredity? Or, stated otherwise, to what extent are children's predictions about parental influence still governed by considerations other than the biological relationship alone?

Method

Participants

One hundred and six children, recruited from day care centres and schools in the city of Amsterdam, participated in the study. Children came from three different age groups, each consisting of 18 boys and 18 girls: 4- to 5-year-olds (M = 5 yrs 2 mths; SD = 3.8 mths); 6- to 7-year-olds (M = 6 yrs 9 mths; SD = 3.5 mths) and 10- to 11-year-olds (M = 10 yrs 9 mths; SD = 3.6 mths).

The testing procedure started with the two oldest age groups. As discussions in the international literature increasingly focus on young children's understanding of biological phenomena, we decided to include an even younger age group later on. At that time, we also decided that some control questions (as will be explained in the Procedure section) should be added to further improve the interpretation of the results obtained. As it was not possible to approach the previously tested children again, the responses to the control questions for the two oldest age groups were gathered from two equally assembled samples (18 males/18 females each) of almost the same age (M = 6 yrs 8 mths; SD = 3.2 mths and M = 10 yrs 7 mths; SD = 3.9 mths, respectively).

Materials and procedure

All children were interviewed individually in a separate, quiet room at school. The first part of the interview consisted of four pairs of questions and a single closing question, presented in a fixed order. All questions asked for a selection of the most likely descendant(s). The first eight questions (four pairs) were accompanied by simple drawings of two biological parents (well-known animals like cats and dogs) and three somewhat smaller drawings representing their possible offspring (see Figure 1).

In the first three pairs of questions, the parents were different on two separate features (for example: ears and whiskers in Figure 1). Only one of the parents was credited with a characteristic from a different domain (as mentioned below). Each pair consisted of an item in which that extra information was attributed to the mother, and an item in which exactly the same information was given about the father. Each time the child had to select the most likely descendant out of three alternatives: two identical versions of the parents (one mother and one father look-alike) and a third alternative that had one of the specific parental features in common with the mother and the other with the father. First, both parents were put next to each other in front of the children (left/right position of father and mother were systematically alternated). Then, the three answering alternatives were positioned in a random way underneath. Whenever a picture was mentioned explicitly in the instruction, the experimenter pointed to the picture in question. The basic instruction was as follows:

> Look, these two cats look different. This is the father-cat. He has big black ear tips and short whiskers. And this is the mother-cat. She has long whiskers and no black ear tips. Together they have had a young kitten. What do you think the little kitten will look like? Will it look like the father, as in this picture? Will it look like the mother, as in this picture? Or will the little kitten have something of both, as in this picture? What do you think? Just point it out for me.

In pair I, we examined a possible bias based on *social proximity*. Therefore the following information was added before the children were asked for their prediction:

> . . . Just after the kitten was born, the father-cat went away. The young kitten and the mother always stayed together. What do you think . . .

A parallel question was asked, which was completely identical to the first one, except for the fact that this time the mother had left and the child was raised by the father. So, in the case of a socially biased answer, we would expect the child to point to the look-alike of the mother in the first question, but to the look-alike of the father in the second one. The two other pairs were constructed in a similar way.

With the extra information presented in the second pair, we examined the possible influence of a variable from the *psychological domain*, i.e., a parental desire. The children were instructed as follows:

> . . . These horses very much wanted to have a young horse, a foal, that would look like the mother, with a beautiful long neck and a short tail. Then they really had a young horse of their own. What do you think . . .

In the parallel question, the parents preferred a look-alike of the father.

In the previous stories, no information was given about the gender of the descendant. This kind of information was introduced explicitly within the next pair of questions, in order to examine a possible bias based on *gender similarity*.

> . . . Together they had a young girl-bird. What do you think . . .

In the parallel question, the birth of a male descendant was announced.

In the last pair of questions, the possible influence of gender was examined in the same way. These questions had exactly the same structure as the previous ones, except for one difference: The parents were different only with respect to one feature (for example, the mother dog had a black coat, whereas the father-dog's hair was white). Children were again presented with a look-a-like of the father, a look-alike of the mother, and a third alternative in which the combined influence of both parents was represented by a *phenotypical new feature*. The question was asked in the following way:

> . . . Will the young girl-dog be a white puppy, like her father? Will she be black like her mother? Or will she be spotted black and white, as in this picture? . . .

Again, in the parallel question, children were asked what a male puppy would look like. Note that the exact wording of the last pair of questions was different from the ones asked previously, in that children were not explicitly told that you can find "something of both" in the third alternative. Without a naive kind of genetic theory about feature combinations, "spotted black and white" may be different from the phrase that was used in the other questions: "something of both". So this time, they had to make that translation for themselves.

In a final question, the matter of phenotypic variability, introduced in the previous pair, was addressed in yet another way. The children were presented with a picture of two large dogs and eight smaller ones. They were told:

> This father and mother dog look completely different. Look, this is the father and this is the mother. Together they had a number of young dogs; a litter of puppies. Underneath, you can see a lot of little dogs. Some of them are children of this father and mother and some of them have other fathers and mothers. Can you point out for me the little dogs that belong to this father and mother?

The two parental dogs, depicted at the top of the page, were different on a number of aspects. Apart from their most salient difference (one was completely black, while the other was completely white), they possessed four further distinctive elements (tail, ears, shape of the head, and coat texture). The eight young dogs were depicted underneath, randomly distributed over the page. Two of them were *identical* to a parent, but only smaller. Two of them, one black and one white dog, possessed a *mixture of parental features* (two characterising elements from the father, combined with two from the mother). The same was the case with the next two young dogs. But this time the most salient feature, the parental colour, was replaced by a *phenotypical new feature* that could easily be imagined as originating from the combined influence of both parents: one of them was coloured grey, whereas the other was spotted black and white. The two remaining young dogs also possessed phenotypical new features. But this time they were *irreducible* to any of the parental characteristics (for instance, one of these dogs had shorts paws, whereas both parents had long ones).

In the youngest group, this initial set of questions was immediately followed by two pairs of *control questions* allowing us to strengthen the interpretation of the results obtained. As explained in the Participants section, in the other two age groups the responses to these questions were acquired from a different but comparable sample.

The first pair of control questions was designed to elicit responses from which we could further examine the issue of domain confusion in young children. It is often suggested that young children are not yet able to cope with the anomalies of psychological testing. They do not anticipate "trick questions" and tend to assume that all information provided by an adult experimenter has to be relevant for the situation at hand (Donaldson, 1978). This testing artefact could facilitate "domain confusion", even when the child is in doubt about whether the information at hand really has an effect on heredity. In order to establish the magnitude of this tendency, we added a couple of questions, in which the additional information was completely *irrelevant*. After the basic instruction, we continued this *irrelevant control* question with:

> ... The father/mother dog has a lot of friends. All the other dogs in the neighbourhood like to play with him/her. The mother/father dog, on the other hand, is often lonely. ...

and in the parallel question with:

> ... The mother/father horse is very strong and can run very fast. The father/mother horse, on the other hand, is often tired. He/she walks very slowly and has to rest several times on the way. ...

Note that popularity and strength have no connection to any feasible childhood conception of heredity. Nonetheless both can be easily used to establish the superiority of one parent over the other. Since the two questions introduced two different types of characteristics, it was necessary to check whether they really could be considered as being parallel questions. Therefore, half of the children within each group were told about a socially superior father and a physically superior mother, and for the other half it was the other way around.

A second pair of control questions was asked since all the questions previously asked allow for the possibility of two different kinds of biases. In each pair of questions, a pair-specific bias may occur (a social bias in pair I, a psychological bias in pair II, a gender bias in pairs III and IV, and a superiority bias in case of the first control question). Alternatively, a mother bias may show up in all of the pairs presented. To discriminate between the two, the questions should be analysed in pairs. In the case of a pair-specific bias, we would expect children to opt for the look-alike of the parent who was credited with the extra characteristic. That is, in one item they will opt for the mother look-alike and in the other for the father look-alike. On the other hand, if they ascribe a dominant influence to the mother, they will select the mother look-alike on both items. However, we should not exclude beforehand the possibility of children being vulnerable to either kind of bias. With the present set-up, it might be that a bias based on the extra information has masked the mother bias. In order to assess the prevalence of the mother bias more accurately, we therefore presented children with an additional pair of questions, in which we gave them the basic *standard control* instruction, as phrased at the beginning of this section, without any further information. Of course, a single question would have sufficed here. However, since all the other questions had to be analysed in pairs (see the results section), we asked the same question twice with respect to different pictorial materials.

Results

The analysis presented is based on the combined answers on the two parallel questions within each question pair. (In the case of the irrelevant information, we first checked whether both questions produced the same results, as different types of information were used here. This indeed proved to be the case, so that this content variable was ignored in further analyses). With three answering alternatives for each question, this results in ($3 \times 3 =$) 9 possible answering patterns. So, with 36 subjects within each age group, a uniform distribution would result in ($36 \div 9$) 4 observations per cell. In Table 1, the observed frequencies of three of these patterns are presented for each

Table 1
Frequencies[a] of criterium-consistent answer patterns within each of the question pairs, by age

	Question-pair					
Pattern[b]	I	II	III	IV	Irr[c]	St[c]
4/5-year-olds						
Social bias	8					
Psychological bias		7				
Gender bias			10	8		
Superiority bias					8	
Mother bias	5	7	6	7	6	11
Combined parental influence	6	8	7	10	9	14
Σ inconsistent patterns	17	14	13	11	12	11
6/7-year-olds						
Social bias	11					
Psychological bias		7				
Gender bias			9	6		
Superiority bias					4	
Mother bias	6	8	7	9	7	10
Combined parental influence	15	13	16	11	14	17
Σ inconsistent patterns	4	8	4	10	11	9
10/11-year-olds						
Social bias	0					
Psychological bias		1				
Gender bias			2	3		
Superiority bias					0	
Mother bias	0	0	0	0	1	5
Combined parental influence	30	24	25	22	32	30
Σ inconsistent patterns	6	11	9	11	3	1

[a] In all cases, the observed number of inconsistent patterns is significantly lower than the expected number under the assumption of a uniform distribution. Within all other patterns, an observed frequency > 7 is significantly higher and an observed frequency < 1 is significantly lower than the expected frequency (4) within a uniform distribution.

[b] First four patterns are pair-specific.

[c] Control questions: Irr = superiority information added, irrelevant to any feasible "heredity theory"; St = basic standard question, without additive information. (In the case of the two oldest groups, these results originated from a new sample—see Method.)

pair of questions. The first pattern represents a pair-specific answering bias: a consistent choice in favour of the descendant identical to the parent who raised the child (social bias; pair I), the parent with the favoured looks (psychological bias; pair II), the parent of the same gender (gender similarity bias; pairs III and IV), or the parent who shows superiority in a completely irrelevant area (superiority bias; irrelevant control pair). More specifically, these observed frequencies indicate a choice of either the father or the mother look-alike within each pair, dependent on which parent was credited with the extra characteristic. (Since no extra information was given in the standard control pair, such a meaningful pattern is absent in this condition). The second pattern of results indicates a general mother bias: a consistent choice in favour of the mother look-alike. And the third pattern represents a consistent choice in favour of the alternative in which the features of both parents are combined. The latter two patterns may be observed among all pairs, including the standard control condition. The remaining possible answering patterns (six for the first four pairs of questions and seven in the case of the standard control condition) are taken together and labelled as inconsistent patterns, meaning that they are not consistent with any of the feasible childhood conceptions of heredity described earlier. None of these so-called inconsistent patterns appeared with a frequency significantly higher than expected under the assumption of a uniform distribution.

Each pair of questions was analysed by a separate log-linear procedure (age by answering pattern), in order to test whether the observed distribution was different from the uniform distribution. This was clearly the case for all pairs: $\chi^2(6, 108) = 52.99$ (pair I); $\chi^2(6, 108) = 28.87$ (pair II), $\chi^2(6, 108) = 33.04$ (pair III); $\chi^2(6, 108) = 21.50$ (pair IV); $\chi^2(6, 108) = 33.66$ (irrelevant control pair) and $\chi^2(4, 108) = 19.98$ (standard control pair). In all cases, $p < .001$. In conformation of our expectations, an inspection of Table 1 shows that the number of choices in favour of the alternative representing a combined parental influence (combined parental influence pattern) increases with age. Even the youngest age group seems to have at least some notion of this general rule of inheritance, as this pattern of results is obtained with almost 40% of the 4/5-year-olds in the standard control condition. However, with respect to the two younger groups, a consistent choice for a combined influence becomes less frequent in response to the other questions. This suggests that their conception of inherited resemblance is still relatively easily affected by information from other domains. Indeed, all of the biases under investigation show up in the answers of both groups. In the case of the youngest age group, even information that can be considered completely irrelevant to the issue of inheritance produces a bias. In the group of 6-year-old children, the superiority bias no longer appears above chance level, but all the other biases are still present. In contrast, the 10- and 11-year-olds clearly acknowledge the irrelevancy of both the superiority information and all the other types of additional information. At this age, any bias caused by information from domains irrelevant to the issue of inherited resemblance is completely absent in most cases. Only incidentally, the mother bias shows up in the standard control condition. We will return to this anomaly in the Discussion.

Age differences regarding the different answering patterns were underpinned by an analysis of contrasts (age 4/5 vs. 6/7, age 6/7 vs. 10/11, and age 4/5 vs. 10/11; $p < .05$, 2-tailed). The results show that children's choice of the alternative reflecting the combined genetic contribution of both parents increases with age. The differences between the two youngest groups only reach significance within pairs I and III, but between the ages of 6 and 10, a marked change is observed on all the pairs.

As expected, the combined parental influence pattern proved to be the only pattern that increases with age. The pair-specific patterns that might indicate the use of an alternative theory are no longer present in the oldest age group. Most changes here seem to occur between the age of 6 and 10. With respect to the social bias (pair I), the psychological bias (pair II), and the gender bias (pair III), the choices of the oldest age group differ significantly from those of the two youngest age groups. No significant differences are found between children aged 4/5 and children aged 6/7. In pair IV, the pair in which offspring with a new phenotypical feature was introduced, age differences, although consistent with the results found with pair III, were less outspoken. Finally, the frequency with which the superiority pattern was found (irrelevant Control pair) differed only significantly between the age of 4/5 and the age of 10/11 (with children aged 6 halfway between).

Unlike the different types of pair-specific biases, the child's acknowledgement of the combined influence of both parents may become evident in all question pairs. This allows for a check on intra-individual consistency. Since the data on the two control pairs were partly collected from different children, we have to limit ourselves to consistency on the four experimental pairs. Complete consistency over those four question pairs was found only for 12 children from the oldest group. But if we use the more lenient criterion of 3 out of 4, our standard of consistency was met by 4 of the 4/5-year-olds, 8 of the 6/7-year-olds, and no fewer than 19 of the 10/11-year-olds. So, even the answers of some of the youngest children seem to reflect a theory-like notion of combined parental influence.

The second answering pattern that may appear on all pairs is the general mother bias. If we exclude the standard control question for a moment, this bias shows roughly the same change with age as the other biases: a significant decrease after the age of 6, so that no bias is found at age 10. The difference between children aged 4/5 and children aged 10/11 just missed significance in the case of pair I and the irrelevant control pair. Nonetheless, within the context of all the other comparisons, the general conclusion that the answers of both of the younger age groups still show a mother bias seems to be justified. As has been argued in the Procedure, children's answers to the questions asked in the standard control condition may reflect a convincing general mother bias. Interestingly, no significant age differences are found on this question pair. Unlike the other biases, then, the mother bias proves to be quite persistent.

If the mother bias is based on a more or less stable theory of heredity, we would expect children who adhere to this theory to use it consistently in their decisions. However, none of the children showed the mother bias in all four experimental pairs, and no more than one (6-year-old) child met the more lenient criterion of 3 out of 4. So, if we want to hold on to the idea that some children use the principle of mother dominance as a general guideline, we have to conclude that its influence is often outweighed by other phenomena. Contrary to the principle of combined parental influence, the dominant position ascribed to the mother seems to reflect a bias more than a theory.

The next issue we would like to address concerns children's acceptance of new phenotypes. Some of the findings discussed previously are of relevance here. Remember that children's answers to question pair IV show roughly the same pattern of results as their answers to question pair III, even though (for reasons explained in the Method) in the former case the third alternative was not explicitly introduced as one reflecting the combined influence of both parents. Apparently, new phenotypes are relatively easily accepted, even by young children.

We now turn to the results obtained with the single closing question, in which the issue of genetic variability and the acceptance of new features was explicitly addressed. Remember that the respondents could select a maximum of two dogs within each appearance category. A 3×4 MANOVA (Age $\times$ Appearance) procedure, with repeated measures on the last variable, showed a main effect of Age, $F(2, 105) = 9.59$, $p < .001$. That is, the number of dogs selected diminishes with age (means: 5.37, 4.50, and 3.60, respectively, out of a maximum of 8). Next to this, a main effect of Appearance was found, $F(3, 315) = 41.36$, $p < .001$; the means are 1.68, 1.15, 1.03, 0.64 for the identical dogs, the dogs with mixtures of parental characteristics, the dogs with new retraceable features, and the dogs with new irreducible features, respectively. Moreover, a marginally significant interaction of Age $\times$ Appearance ($p = .10$) showed that age differences were not identical for each of the appearance categories. Separate ANOVAs on children's choices for each of the four types of appearances showed only a significant effect of Age in the case of the dogs with new irreducible features, $F(2, 105) = 8.83$, $p < .001$. The two youngest age groups chose dogs from this appearance category significantly more often than the oldest age group (means: 0.94, 0.72, and 0.25, respectively; ps $< .05$). In sum, these results suggest that children from all age groups easily accept new phenotypes. However, both 4- and 6-year-old children's answers did not show the same limitations to the concept of genetic variability as those of 10-year-olds, as they also relatively frequently selected dogs with new features that cannot be reduced to parental characteristics. Ten-year-olds rarely chose these far-fetched alternatives.

Discussion

The results clearly indicate that a conception of heredity in which the combined influence of both parents is acknowledged grows with age. Although even some of the youngest children more or less consistently prefer a descendant in which characteristics of both parents are united and thus seem to have developed a theory-like conception in this sense, it is not until the age of 10 that most participants consistently react in this way. Moreover, it has been shown that it is only in this older age group that information from other domains is clearly considered irrelevant. In contrast, younger children (6/7-year-olds and 4/5-year-olds alike) still seem to be susceptible to domain confusion to some extent (e.g., Carey, 1985; Piaget, 1929), as they erroneously use information from other domains to decide on the superiority of one parent over the other.

To be credited with a domain-specific (i.e., biological) theory of heredity, children need to understand that it is the biological relationship that is critical for the inheritance of properties. The age differences found in the present study are consistent with the developmental findings of Solomon et al. (1996), in the sense that children aged 7 or younger still tend to explain the inheritance of physical properties by social proximity and psychological considerations; variables that are irrelevant to a biological theory of heredity. Moreover, the other types of information included in this study (gender similarity, and the identity of the mother) did produce a similar effect.

In our opinion, it is not very useful to directly compare the different types of domain confusions at hand. One reason for our reluctance in this respect has already been addressed: The same piece of information may refer to different domains. The effect of gender (dis)similarity, for instance, can be explained along biological as well as social or cultural lines. Likewise, a general mother-bias may originate from biological proximity ("children come from their mothers' tummies"), but social considerations may exert an effect as well ("Mothers and their children are much more often together"). Explanations referring to different domains are almost impossible to disentangle. Next, the results show that the different types of information presented equally often cause confusion (see Table 1). In each case, roughly one out of four children chose a look-alike of the parent credited with the extra characteristic. This seems to suggest a *general* vulnerability in children's theorising rather than their being susceptible to *specific* domain confusions.

Before we address the nature of this vulnerability any further, we first have to present the various positions in the literature on the acquisition of a framework theory of biology. Springer (1995, 1999) distinguishes two types of proposals. Type 1 links the emergence primarily to innate predispositions (e.g., Keil, 1989, 1994; Wellman & Gelman, 1992), whereas Type 2 assumes that a naive theory of biology is derived from other framework theories (e.g., Carey, 1985). The latter type implies that naive biology emerges through a variety of processes, including the acquisition and reorganisation of biological knowledge. However, as Springer (1999) points out, the differences are merely a matter of emphasis: Type 1 theorists do not deny the importance of experience and Type 2 theorists acknowledge the possibility of genetic constraints on theory acquisition. Springer suggests a third type of theoretical stance (a combination of both): The child's acknowledgement that babies grow inside the mother marks the beginning of a naive theory of biology. This knowledge allows children to make *theoretically based* (though sometimes incorrect) predictions about the phenotype and (equally often incorrect, but internally consistent) notions about inheritance. In short, "learning about an unseen process changes children's understanding of observable features" (Springer, 1999, p. 47).

With Springer's type of reasoning in mind, we questioned our youngest participants at the end of each session about the role of the mother in procreation. Somewhat unexpectedly (Goldman & Goldman, 1982), we found that all children, but for one exception, proved to be clearly aware that children "come from their mothers' tummies". Maybe Dutch children are advanced in this sense, or general knowledge has improved over the last 20 years. Anyway, this outcome made it impossible to use this question as a way to check Springer's claim about the critical importance of this kind of knowledge. Nonetheless, with this precondition fulfilled, the results seem to fit Springer's developmental ideas. The consistency of the answer patterns increases with age, suggesting an increasing amount of theory-based reasoning. Initially, most of these theories are still incorrect. Type 1 theorists may like to point out that a significant proportion of even the youngest group seems to have an intuitive understanding of a combined parental genetic influence. Type 2 theorists, on the other hand, will probably stress the fact that their answer pattern is still often disturbed by nongenetic considerations. Springer's explanation would have been that their experience-based knowledge may still have guided these children in the wrong direction: people often succeed in making their wishes come true; the rearing process does increase the number of shared characteristics between parent and child; and gender similarity does imply a number of shared gender characteristics. Later on, when their genetic reasoning becomes more integrated and coherent, they become able to question the relevancy of this local knowledge.

Before we ask ourselves the question of how genetic reasoning changes over time, we have to point out the possibility that, even without the theoretical notion of a combined genetic influence of both parents, the experience-based knowledge of young children might have pushed them in the direction of the correct answer alternative. Later on, we will discuss the fact that the notion of genetic variability seems to be acknowledged quite early in life. In itself, this notion could have been sufficient to reject the two carbon copies as possible alternatives. Indeed, in everyday life, it is extremely unlikely that a child perfectly resembles one of the parents. In an unpublished study by Springer (reported in Springer, 1999), it was found that children acknowledge this fact: They expressed the opinion that the baby will never look exactly like either parent in shape, colour, and probably most importantly, size. Our three offspring alternatives were all smaller in size but, strictly speaking, it is still possible to argue that a choice in favour of the third alternative merely reflects a rejection of the other two on the basis of genetic variability. However, the closing question that specifically addresses the variability topic reveals no age differences in the acceptance of both carbon copies and offspring with mixed features. Therefore, the increasing preference for the latter alternative cannot be sufficiently explained by a growing acceptation of new phenotypes and/or a rejection of the possibility that children exactly resemble a parent. It has to be attributed to an improvement of genetic reasoning.

As was pointed out at the start, the first important step in genetic reasoning is the application of the "like-begets-like" principle. Although children already tend to use this principle relatively early in life (Springer & Keil, 1989), it is quite likely that they apply this rule in a rigid way. This might cause them to prefer a carbon copy of one of the parents over the no more than partial resemblance resulting from the combined influence of both. They still, however, have to make a choice between the two carbon copies. This makes it tempting to use the additional information, as long as they still think it possible that this information is relevant. This two-step decision-making process exactly fits the findings in the two youngest groups, although only the 4-year-olds still use the kind of information that does not fit into any feasible theoretical conception of heredity. This is consistent with Donaldson's (1978) suggestion that the testing procedure per se might have been confusing for them. They might have automatically concluded that the experimenter expected them to use all information provided.

A choice in favour of the third option could be strengthened in a positive way: by the conception that both parents have an impact on their descendants; and a negative one: by the dismissal of the additive information as theoretically unsound. Both considerations are directly related to the strength of children's theorising about the inheritance of properties, but strictly speaking the present set-up does not allow for a conclusion about the strength of the former factor. However, the results are quite clear about the latter one. Whereas 4-year-olds used *any* information to decide for the superiority of one parent over the other, 6-year-olds' answers were no longer influenced by the information presented in the "irrelevant" condition. Only the 10-year-olds, however, were able to resist all information from other domains.

An interesting finding concerns children's preference for a carbon copy of the mother. In the Results, we have shown that although a choice for a carbon copy of the mother occurs consistently *within* pairs (the prevalence of the answering pattern referred to as the "mother bias"), no such consistency was found *over* pairs. Rather than a dominant early theory of heredity (Springer, 1995, 1999), the mother bias, just like all other biases, seems to reflect a general vulnerability of genetic reasoning during this early stage. Just like the other biases, the mother bias has disappeared at age 10, but for one exception: Its influence is still noticeable on the answers to the standard control question—the only question that lacks additional information. The acknowledgement that this type of information is irrelevant may have triggered a new formal rule, which caused the participants to be extra careful not to use anything other than the newly acquired genetic principle that both parents exert an equal genetic influence. So it seems that, without this kind of prime, children are still tempted to base their answers on implicit notions about the relative importance of the mother.

Our results regarding the mother bias, was shown which under certain conditions, even among 10-year-olds, corroborates earlier findings (Clough & Wood-Robinson, 1985; Karbo et al., 1980) and suggests that, in this case, we are dealing with a persistent phenomenon. Within this context, it might be illustrative to mention the outcome of a post hoc survey, which suggests that mother dominance persists long after the age of 10. We presented the standard control question to a number of students. As we expected, all of them selected the third alternative (combined features) as the most likely offspring. Nonetheless—although we may take it that their formal education has taught them differently—a few of them added spontaneously that children normally have a somewhat stronger resemblance to their mother. The exact reason for this idea remains obscure. It might be a reflection of the central position ascribed to the mother in anything related to children, which then causes *over-generalisation* of the notion of dominance of the mother over the father. But it could also be that we simply have to regard the phenomenon as an unconscious remnant of our earliest childhood theory of inheritance. Whatever the reason for such a nonrational choice, the observation in itself suggests that domain confusions or theoretical inconsistencies probably never disappear completely.

Just as the choice of the third alternative does not exclude all biases, when it is governed by the idea that the offspring has to show at least some characteristics of each parent, the choice of a carbon copy does not automatically imply that the child has no notion of genetic variability. The participants had only three options, which may not have fitted their ideas completely. The closing question was less limited in options. Indeed, even on this question, young children show a relative preference for a perfect look-alike. But they clearly do not reject the idea of genetic variability altogether and select a substantial number of dogs other than the perfect carbon copies. Obviously, they are not completely ruled by the principle that "like begets like" or they would have rejected the whole concept of genetic variability. Instead, we see that the phenomenon as such is accepted relatively early in life. It is quite easy to observe that children never completely resemble a parent. So the basic idea of genetic variability is probably derived from personal experience. However, it is doubtful whether young children really understand the underlying principles. Contrary to 10-year-olds, both 4- and 6-year-olds quite often selected dogs with new irreducible features, which suggests a poor understanding of the limitations of phenotypic variance.

The general principles of heredity are almost impossible to learn by observation alone. Physical similarities between parents and children, for instance, are much harder to observe than is often taken for granted (Christenfeld & Hill, 1995). Verbal communication is probably an influential factor in constructing a theory of heredity (Inagaki, 1990). The children themselves are the eliciting stimuli for conversations on this topic. Sociobiology teaches that the survival of genetic material is one of the main motives behind the behaviour of all species. This makes it understandable that parents are eager to detect concrete evidence for the survival of their genes (Meerum Terwogt, Hoeksma, & Koops, 1993). Even before they have left the cradle, young children are exposed to numerous messages that contain relevant information about this biological phenomenon. Again and again, they have listened to statements like "Look, he has his father's nose", or "She is the perfect image of her mother". When we bear this in mind, it is not surprising that the general idea that children have something in common with their parents develops quite early in life. We do not need to assume some kind of inborn understanding of heredity for this. The "like begets like" principle is the most simple and direct translation of this resemblance conception.

The present experiment has shown that a substantial number of the 4- and 6-year-old children still fail to adapt this rule to a two-fold situation. The "like begets like" principle may have put them on the wrong track and made it difficult for them to ignore a perfect resemblance to one parent, in favour of a no more than partial resemblance to both parents. As we pointed out, this phenomenon cannot be taken as hard evidence that these children fail to understand completely that *both* parents contribute to the physical appearance of their children. In fact, a somewhat different testing procedure, like the one that was used in the closing question, suggests otherwise. Nonetheless, even when we realise that the experiment is a rather severe test of children's knowledge, since it is effectively designed as a kind of counter-suggestion procedure, it is legitimate to conclude that 4- and 6-year-old children are still easily confused by the presence of information that would be considered irrelevant only in the case of a firm, well-defined conception of heredity.

The age differences observed in this experiment do not give grounds for a radical view of restructuring (Kuhn, 1962) in the area of heredity. In that case, we would have expected a developmental shift: A more or less fixed transition period in which the child changes core concepts and consequently moves on from one knowledge system to another. The data rather suggest a progressive incorporation of knowledge elements and a gradual growth to a more restricted and a better defined conception of the principles of heredity. However, the possibility of developmental shifts cannot be excluded completely for at least two reasons. First, we have not studied the individual pathways of development. If the accumulation of individual experience is the main reason for these conceptual shifts, as Springer (1999) suggests, we cannot expect them to take place at a fixed moment in life. Individual transitions might have been masked by the fact that we are comparing age groups. Second, the strongest development clearly takes place between age 6 and 10; an age gap that is still quite large. Future research should focus more on the years in between in order to determine what exactly happens during that period.

Manuscript received September 2001
Revised manuscript received February 2003

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